Significant Events Reported by the NDBC Stations during Hurricane Katrina

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***Abstract*- The National Data Buoy Center (NDBC) Ocean Observing System consists of buoys and Coastal Marine Automated Network (C-MAN) stations making routine, continuous reports of meteorological and oceanographic conditions. The routine reporting of the system assumed a significant role in providing real-time, continuous, on-scene observation to the forecasters of the National Weather Service and the public, as Hurricane Katrina powered its way across southern Florida and through the Gulf of Mexico. This paper describes significant events, associated with Hurricane Katrina, reported by NDBC stations. Significant events include record-breaking winds and seas across the broad expanse of the Gulf of Mexico, the employment of new platforms and capabilities, and casualties to the system.**

I. Prelude

After a very active 2004 Hurricane Season, 2005 continued with an unprecedented pace of tropical cyclone development for the Atlantic in July [1]. August continued the trend with above average tropical cyclone development [2]. Despite this enormous potential for destruction, as late August approached, the National Data Buoy Center (NDBC) had 33 of its 34 stations in operation in the Gulf of Mexico and east coast of Florida. The only inoperable station was at Lake Worth, Florida (LKWF1) because damage to the public pier earlier in the 2004 Hurricane Season prevented access to repair the station when it failed in October 2004.

In addition to the regular network of stations, in 2005 the National Oceanic and Atmospheric Administration (NOAA) had funded NDBC to build and deploy seven hurricane supplemental buoys, one of which was stationed in the Bay of Campeche.

NDBC's network of moored buoys and Coastal-Marine Automated Network (C-MAN) stations of the Gulf of Mexico and eastern Florida had already provided valuable observations for the above average number of Atlantic tropical cyclones in the first part of the 2005 Hurricane Season and stood ready to provide more for the remainder of the 2005 Hurricane Season.

II. Data Availability

In its forecast/advisory messages, the National Hurricane Center (NHC) issues a request for 3-hourly ship observations within 300 nautical miles of a tropical cyclone center [3]. Twenty-eight NDBC stations (Fig. 1) provided over 1500 meteorological, oceanographic, and wave reports in real-time within 300 nautical miles of Hurricane Katrina from its inception as a tropical depression on 23 August 2005, through

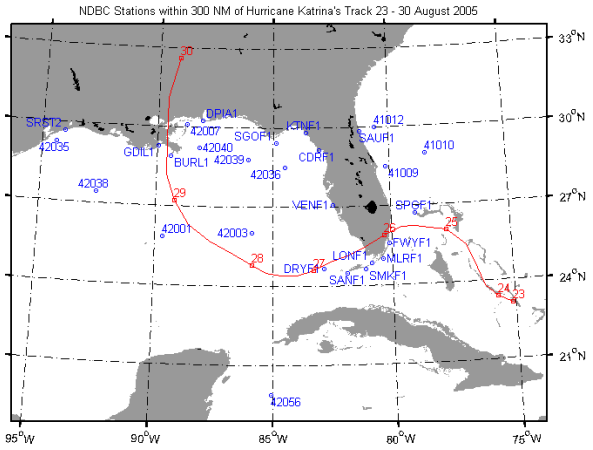

Figure 1. NDBC Stations within 300 Nautical Miles of Hurricane Katrina's Track

its intensification to a Category 5 hurricane, and to its landfall on 29 August 2005. NDBC stations routinely provide meteorological observations of sea-level pressure, sustained winds and gusts, air, and sea surface water temperature at least every hour. Two stations, 41009 and 41010, provide meteorological observations very 30 minutes.

All NDBC buoys make wave height measurements at least once an hour, sampling over either 20 or 40 minutes. Many of the wave height measuring buoys also provide wave directional information. C-MAN stations at Dauphin Island, AL (DPIA1), Long Key, FL (LONF1), and Sombrero Key, FL (SMKF1) provide water-level measurements. NDBC provides subsurface oceanographic measurements at Fowey Rocks, FL (FWYF1), and hosts oceanographic instrumentation provided by the Florida Institute of Oceanography at LONF1, SMKF1, and Sand Key, FL (SANF1).

NDBC disseminates its observation within minutes of the observation by posting the data to its web pages (http://www.ndbc.noaa.gov) and making them available to the Global Telecommunications System (GTS). NDBC formats its buoy observations in World Meteorological Organization's alphanumeric formats, and its C-MAN data in the CMAN message format. NDBC supplements observations from its system with observations from 38 stations operated by a variety of partners.

III. Wave Observations

Katrina's extensive coastal flooding was caused by the enhancement of an already massive storm surge by wave setup

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[4], including the reported significant wave height of 16.91 meters reported by station 42040 at 1100 UTC on 29 August 2005 (Fig. 2). The 16.91-meter report is the highest significant wave height reported by an NDBC buoy in the Gulf of Mexico and surpassed the 15.96-meter report from the same station during the passage of Hurricane Ivan in September 2004. 16.91 meters also matches the previous highest significant wave height reported by an NDBC buoy reported by station 46003 (in the Northeast Pacific Ocean south of the Aleutian Islands) in January 1991.

At the time of the 16.91-meter report, Hurricane Katrina was 135 kilometers west of the buoy moving northwards at 24 kilometers per hour. Katrina's central pressure one hour later at 1200 UTC was 923 hectoPascals with maximum sustained one-minute wind speed of 56.6 meters per second (110 knots).

Maximum significant wave heights reported by 42040 during Hurricane Ivan in 2004 verified well [5] with the practical formula for estimating significant wave height from minimum pressure [6]:

$$H_{smax} = 0.2*(1013 - P_o) \quad (1)$$

where:

H_{smax} is the maximum significant wave height in meters, and

P_o is the hurricane's minimum central pressure in hectoPascals.

For Katrina and 42040, the minimum central pressure at the time of the 16.91-meter report was approximately 923 hectoPascals - that would result in a maximum significant wave height of 18 meters using (1), slightly more than reported. This is probably consistent with seas being generated closer to the radius of maximum winds than 42040's position relative to Katrina.

The Department of Interior's Mineral Management Service (MMS) sponsors 42040, which is located approximately 119 kilometers south of Dauphin Island Alabama in water 274 meters deep. Station 42040 is a three-meter aluminum discus hull tethered to an anchor at the ocean bottom using an inverse catenary mooring. NDBC buoys return the spectral densities derived from the transformation of acceleration measurements in the time domain into the frequency domain using a Fast Fourier Transform. Further details on the analysis and processing of wave data can be found in Reference [7]. The 3-meter buoy at 42040 measures the vertical acceleration of the buoy hull using a fixed accelerometer (Schaevitz LSOC-30 Inclinometer) calibrated and installed in October 2004. The onboard system, the Data Acquisition and Control Telemetry Directional/Wave Analyzer (DACT/DWA) samples accelerations at a rate of 2.0 Hertz for 20 minutes beginning at 20 minutes after the top of each hour. NDBC had installed a new DACT DWA onboard 42040 in July 2005. In addition, six buoys reported seas 12 feet and greater for more than 24 hours, and 12-foot seas extended into extreme western Gulf of Mexico, and seas nearly 7 feet were pushed through the Yucatan Channel to be measured by station 42056.

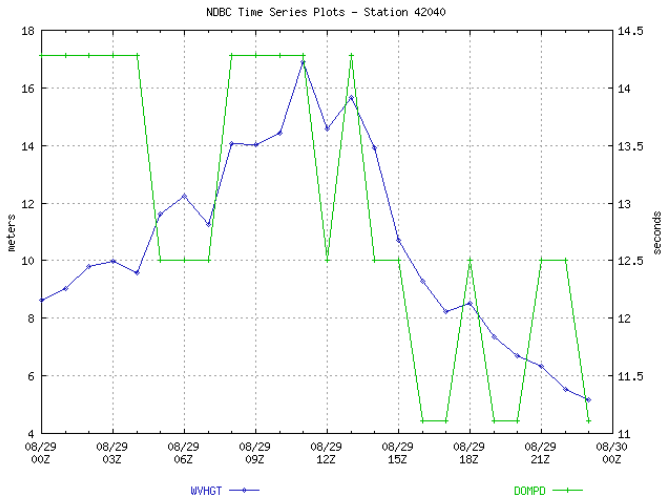

Figure 2. Significant Wave Height (WVHGT) and Peak Period (DOMPD) at 42040

In addition, six buoys reported seas 12 feet[1] and greater for more than 24 hours, and 12-foot seas extended into extreme western Gulf of Mexico. Seas nearly 7 feet were pushed through the Yucatan Channel to be measured by station 42056 (Fig. 3, Above the station location marker are highest significant wave height in feet, and below, are the number of hours of waves 12 feet or).

Katrina's winds and seas capsized the 96-ton, 12-meter diameter buoy at station 42003. Before the capsizing, the National Hurricane Center used that station's reports (Fig. 4).to extend the radii of 12-foot seas early on 27 August 2005 [8]. Katrina also broke the mooring of the buoy at station 42007 (a 3-meter discus buoy) on 29 August 2005. However, the buoy kept reporting as it was driven ashore during landfall. As the winds veered from the unlimited wave fetch of the East and South and then to the fetch-limited West (Fig. 5), peak periods correspondingly dropped from the 5-6 seconds to 2-3 seconds (Fig. 6).

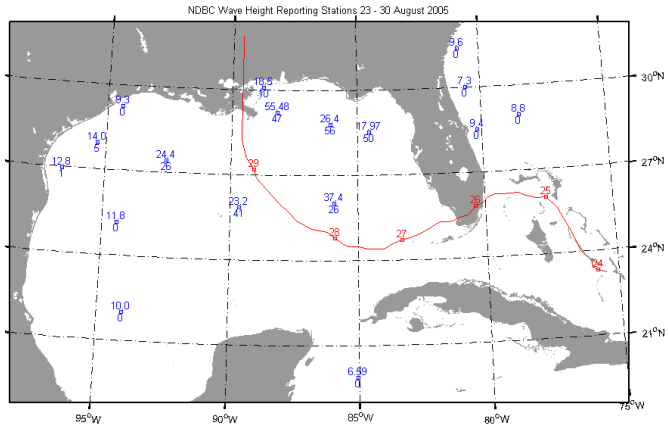

Figure 3: Highest Waves (feet) and Hours of 12-foot Seas

[1] Feet are used because National Hurricane Center provides radii of 12-foot seas in its warnings.

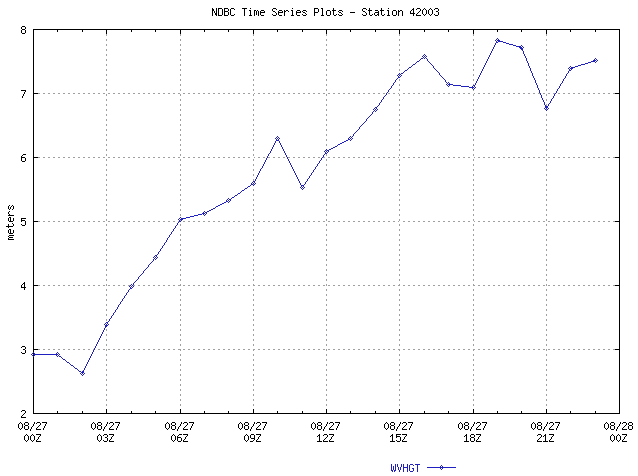

Figure 4. Significant Wave Heights (WVHGT) from Station 42003 before Capsizing

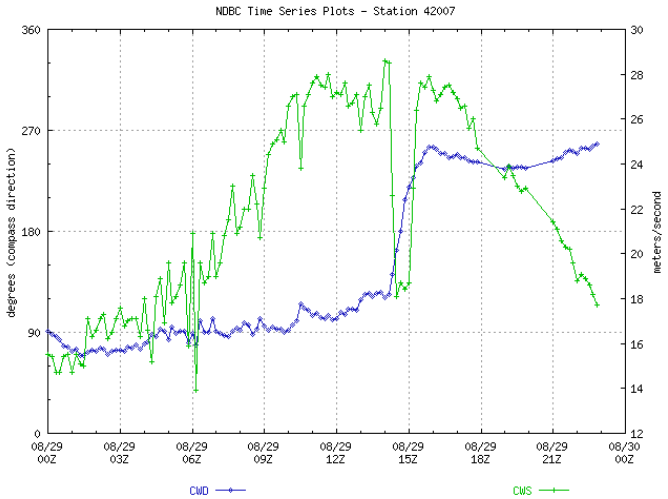

Figure 5. Continuous Wind Direction (CWD) and Speeds (CWS) for Station 42007

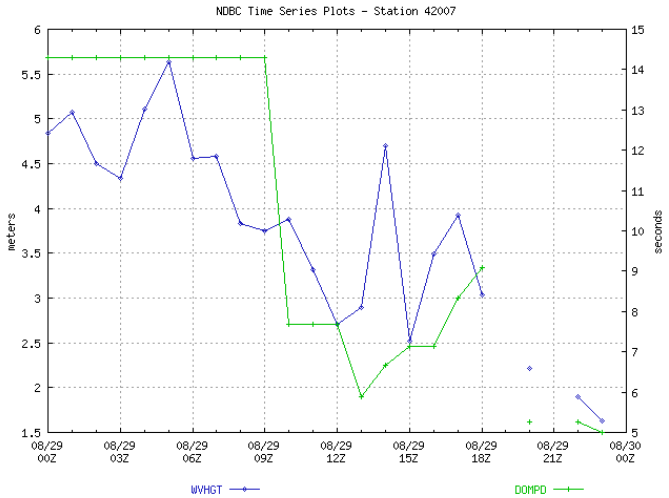

Figure 6. Wave Height (WVHGT) and Peak Period (DOMPD) of 42007

IV. EVENT RECORDS

Many NDBC stations in the eastern and north-central Gulf of Mexico exceeded annual and monthly extremes for highest wind speed and lowest pressure (Table 1). Katrina's record-setting trends began in the Florida Keys as it transited the Florida Peninsula and emerged into the southeast Gulf of Mexico as C-MAN stations in the lower and middle Keys set new monthly records for August. Records then accompanied Katrina across the Gulf of Mexico, and even reached close to the Texas coast where Buoy 42019 set a record for lowest sea-level pressure for August.

The three NDBC C-MAN stations closest to Katrina's track, Dry Tortugas FL (DRYF1), Buras (Southwest Pass) (BURL1) and Grand Isle (GDIL1) LA, set new extremes for sea-level pressures, highest sustained (2-minute average) winds, and highest 5-s gusts for their periods of record. Katrina passed between BURL1 and GDIL1 as it made its first landfall. early on 29 August 2005.

At BURL1, data transmissions ceased after 0500 UTC, as its winds and sea-level pressure reached their record extremes (Fig. 7). GDIL1's wind sensors failed, but it continued to report sea-level pressure (Fig. 8).

V. SUPPLEMENTAL MEASUREMENTS

Prior to the 2005 Hurricane Season, the National Oceanic and Atmospheric Administration provided funding to deploy seven buoys in the western Tropical Atlantic, the Caribbean Sea, and Gulf of Mexico. NDBC coordinated site selection and measurement requirements with the National Hurricane Center. Among the seven new buoys, NDBC established new stations in the Bay of Campeche (Buoy 42055) and the Yucatan Channel (Buoy 42056). All seven buoys were specially configured for additional measurements of highest one-minute wind speed and the lowest pressure during every hour with a complete independent backup suite of sensors and communications. Although 42055 and 42056 were on the periphery of Hurricane Katrina, the new measurements provided continuity of observations and captured extremes outside of the normal 8-minute observing window.

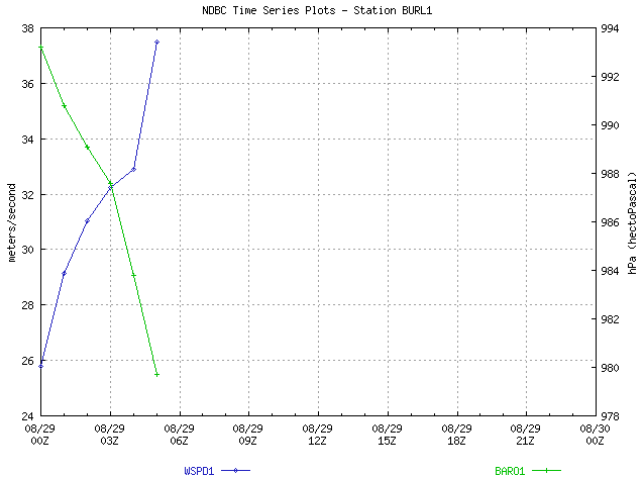

Figure 7. 2-minute Sustained Winds (WSPD1) and Sea-level Pressure at Buras (Southwest Pass)

TABLE 1
EVENT RECORDS AT NDBC STATIONS ASSOCIATED WITH THE PASSAGE OF HURRICANE KATRINA

Location	Station ID	Start Period of Record (POR)	Type Of Event	New Value	Old Value: Year Month
C-MAN Molasses Reef FL	MLRF1	1987	Highest 2-minute Wind Speed for August	27.3 m/s	24.6 m/s: 1998
C-MAN Molasses Reef FL	MLRF1	1987	Highest 5-second Gust for August	34.5 m/s	28.7 m/s:
C-MAN Long Key FL	LONF1	1992	Lowest Sea-Level Pressure for August	1000.2 hectoPascals	1006.5 hectoPascals: 1995
C-MAN Long Key FL	LONF1	1992	Highest 2-minute Wind Speed for August	22.0 m/s	15.4 m/s 1994
C-MAN Long Key FL	LONF1	1992	Highest 5-second Gust for August	26.1 m/s	18.1 m/s: 1994
C-MAN Sombrero Key FL	SMKF1	1991	Lowest Sea-Level Pressure for August	1005.0 hectoPascals	1007.2 hectoPascals: 1995
C-MAN Sombrero Key FL	SMKF1	1991	Highest 2-minute Wind Speed for August	25.8 m/s	18.8 m/s: 2001
C-MAN Sombrero Key FL	SMKF1	1991	Highest 5-second Gust for August	29.9 m/s	19.0 m/s: 2001
C-MAN Sand Key FL	SANF1	1991	Lowest Sea-level Pressure for August	999.7 hectoPascals	1007.1 hectoPascals: 1995
C-MAN Dry Tortugas FL	DRYF1	1992	Lowest Sea-Level Pressure POR	974.4 hectoPascals	981.3 hectoPascals: 1998 Sep
C-MAN Dry Tortugas FL	DRYF1	1992	Highest 8-minute Wind Speed POR	36.6 m/s	30.4 m/s: 1998 Sep
C-MAN Dry Tortugas FL	DRYF1	1992	Highest 5-second Gust POR	43.3 m/s	34.9 m/s: 1998 Sep
Buoy 22 nm SSE of Biloxi MS	42007	1981	Lowest Sea-level Pressure for August	996.2 hectoPascals	1004.3 hectoPascals: 1988
Buoy 22 nm SSE of Biloxi MS	42007	1981	Highest Significant Wave Height for Aug	5.6 m	3.4 m: 1985
Buoy 260 nm S of Panama City FL	42003	1976	Highest 2-minute Wind Speed for Aug	28.6 m/s (Last before capsize)	23.4 m/s: 1992
Buoy 260 nm S of Panama City FL	42003	1976	Highest 5-s Gust for Aug	32.6 m/s (Last before capsize)	30.6 m/s: 1992
Buoy 260 nm S of Panama City FL	42003	1976	Highest Significant Wave Height for Aug	10.6 m	6.4 m: 1992
Buoy 260 nm S of Panama City FL	42003	1976	Lowest Sea-Level Pressure for Aug	987.8 hectoPascals	997.4 hectoPascals: 1992
Buoy 180 nm S of Southwest Pass LA	42001	1975	Lowest Sea-Level Pressure for Aug	981.3 hectoPascals	1003.1 hectoPascals: 1980
Buoy 64 nm S of Dauphin Island AL	42040	1995	Highest 5-second Gust for POR	35.0 m/s	34.8 m/s: 1998 Sep
Buoy 64 nm S of Dauphin Island AL	42040	1995	Highest 8-minute Wind Speed for POR	28.1 m/s	27.9 m/s: 1998 Sep
Buoy 64 nm S of Dauphin Island AL	42040	1995	Highest Significant Wave height POR	16.91 m	15.96 m: 2004 Sep
C-MAN Buras LA	BURL1	1989	Lowest Sea-Level Pressure for POR	979.7 hectoPascals	981.8 hectoPascals: 1985 Oct
C-MAN Buras LA	BURL1	1989	Highest 2-minute Wind Speed for POR	37.5 m/s	32.7 m/s: 1995 Oct
C-MAN Buras LA	BURL1	1989	Highest 5-second Gust for POR	42.9 m/s	37.2 m/s: 1995 Oct
C-MAN Grand Isle LA	GDIL1	1984	Lowest Sea-Level Pressure for POR	944.3 hectoPascals	987.2 hectoPascals: 1985 Oct
C-MAN Grand Isle LA	GDIL1	1984	Highest 2-minute Wind Speed for POR	33.7 m/s	27.3 m/s: 1997 Jul
C-MAN Grand Isle LA	GDIL1	1984	Highest 5-second Gust for POR	45.6 m/s	30.1 m/s: 1992 Aug
C-MAN Dauphin Island AL	DPIA1	1987	Lowest Sea-Level Pressure for August	986.1 hectoPascals	1000.5 hectoPascals: 1995
C-MAN Dauphin Island AL	DPIA1	1987	Highest 2-minute Wind Speed for August	33.9 m/s	18.8 m/s: 1988
C-MAN Dauphin Island AL	DPIA1	1987	Highest 5-second Gust for August	42.8 m/s	22.5 m/s: 1995
Buoy 115 nm SSE of Pensacola FL	42039	1995	Highest Significant Wave Height for August	8.13 m	5.6 m: 2001
Buoy 106 nm WNW of Tampa FL	42036	1994	Highest Significant Wave height for August	5.48 m	4.6 m: 1999
Buoy 60 nm S of Freeport TX	42019	1990	Lowest Sea-Level Pressure for August	1000.9 hectoPascals	1007.1 hectoPascals: 1998

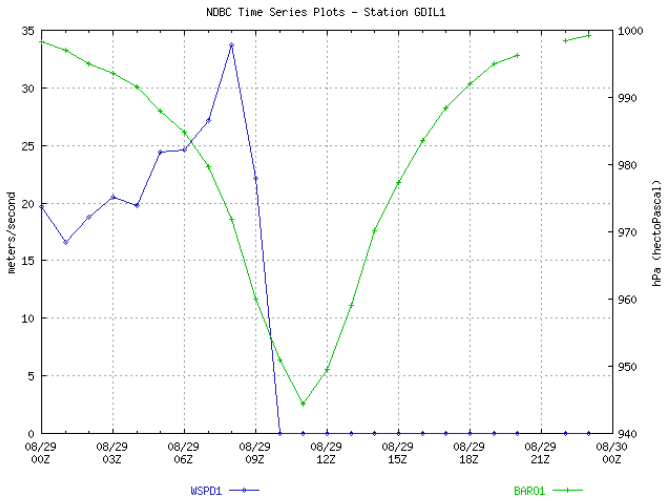

Figure 8. 2-minute Wind Speed (WSPD1) and Sea-Level Pressure for Grande Isle LA

In addition to its own network of buoys and coastal marine stations, NDBC receives observations from partner organizations and distributes them in the same manner as NDBC stations via the National Weather Service Telecommunications Gateway. This is done to help fill in the gaps between NDBC stations and make observations from these stations available to a broader spectrum of the meteorological community including National Weather Service Forecast Offices, the Tropical Prediction Center, local television broadcasters and emergency managers. Partner organizations include National Ocean Service's Center for Operational Oceanographic Products (CO-OPS) and Services that provides meteorological observations from their Water Level Observation Network, academic institutions, and other state and local observing systems.

During the landfall of Katrina in Florida and the Gulf Coast these stations were a valuable real-time augmentation to the NDBC array of stations, adding an additional 35 marine stations that were within 300 miles of Katrina's track. These included marine coastal stations and moorings operated by CO-OPS, the University of South Florida, the University of Southern Mississippi, the Louisiana Universities Marine Consortium, Louisiana State University, and Texas A and M University.

NDBC also received and distributed meteorological and oceanographic observations from oil drilling and exploring platforms operated, as stations 42361 and 42362, by Shell Oil International Exploration and Production in the north central Gulf until they were evacuated for safety reasons as Katrina entered the Gulf. Station FGBL1, operated by Forest Oil, provided wind observation until early on the 29th.

VI. Aftermath

The NDBC Ocean Observing System provided a host of real-time observations spanning the length and breadth of the area affected by Hurricane Katrina. NDBC stations provided near continuous, *in situ* observations in real-time. Despite the enormous destruction associated with Katrina, only four NDBC stations remained inoperable from Katrina's passge. By early October, a 6-meter buoy had replaced the capsized 42003 - in time to provide observations as Hurricane Wilma moved through the southeastern Gulf of Mexico and made landfall in Florida. 42007 was recovered and redeployed by late September. BURL1 was restored in late December. Because of the extensive damage to the Coast Guard station hosting GDIL1, it remains out of operation.

LKWF1 was eventually relocated near its former location in June 2006. MMS did not renew its sponsorship of 42038, and the station was not re-established after it broke its mooring in early 2006. So as a very active 2006 Hurricane Season approaches [9], GDIL1 is the only remaining casualty of Hurricane Katrina.

References

[1] National Hurricane Center, *Monthly Tropical Weather Summary*, August 1, 2005. [Available on-line at http://www.nhc.noaa.gov/archive/2005/tws/MIATWSAT_jul.shtml?]

[2] National Hurricane Center, *Monthly Tropical Cyclone Summary*, September 1, 2005. [Available on-line at http://www.nhc.noaa.gov/archive/2005/tws/MIATWSAT_aug.shtml?]

[3] Office of the Federal Coordinator for Meteorological Service and Supporting Research, *National Hurricane Operations Plan, FCM-P12-2006*, Washington, DC, 2006, p. 4-4. [Available on-line at: http://www.ofcm.gov/nhop/06/nhop06.htm]

[4] R.D. Knabb, J.R. Rhome, and D.P. Brown. *Tropical Cyclone Report, Hurricane Katrina, 23-30 August 2005*, National Hurricane Center, Miami, FL, 2005. [Available on-line at: http://www.nhc.noaa.gov/pdf/TCR-AL122005_Katrina.pdf]

[5] G.W. Stone, N.D. Walker, S.A. Hsu, A. Babin, B. Liu, B.D. Keim, W. Teague, D. Mitchell, and R. Leben, "Hurricane Ivan's Impact Along The Northern Gulf of Mexico," *Eos*, vol. 86(48), pp. 497-508, 2005. [Available on-line at: http://wavcis.csi.lsu.edu/pubs/Ivan.EOS.29nov.pdf

[6] S. A. Hsu, M.F. Martin Jr., and B.W. Blanchard, 'An evaluation of the USACE's deepwater wave prediction techniques under hurricane conditions during Georges in 1998", *J. Coastal Res*., vol. 16(3), pp.823-829, 2000.

[7]] National Data Buoy Center, *Nondirectional and Directional Wave Data Analysis Procedures, NDBC Technical Document 96-01*, Stennis Space Center, MS: National Data Buoy Center, 1996, p. 26. [Available on-line at: http://www.ndbc.noaa.gov/wavemeas.pdf]

[8] NWS TPC/National Hurricane Center, *Hurricane Katrina Discussion Number 16 5 am EDT Sat Aug 27 2005*. [Available on-line at: http://www.nhc.noaa.gov/archive/2005/dis/al122005.discus.016.shtml]S.

[9] National Oceanic and Atmospheric Administration, *NOAA: 2006 Hurricane Outlook*, NOAA Press Release 22 May 2006. [Available on-line at http://www.cpc.ncep.noaa.gov/products/outlooks/hurricane.shtml]